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SOIL-MOISTURE TRENDS UNDER VARYING DENSITIES OF OAK OVERSTORY

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Typical post oak stands, averaging 65 square feet of basal area per acre, were thinned, left undisturbed, or clearcut prior to observation of soil-moisture trends. The stand pictured here was subsequently thinned to 26 square feet of basal area per acre.

SOIL-MOISTURE TRENDS UNDER VARYING DENSITIES OF OAK OVERSTORY[1]

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Plant growth, including the growth of forests, is profoundly affected by intricate interactions between the soil, the soil moisture, and the plants themselves. Understanding of so complex a relationship can be acquired only a little at a time as studies can be conducted in various soil types and different cover conditions.

Phases of these relationships were studied on one important soil type near College Station, Texas, in oak stands that had been thinned to three levels of basal area in a forage-production study. Electrical-resistance units were used to measure soil-moisture content in three soil horizons from May 1953 to August 1954. Laboratory determinations of physical soil characteristics afforded a basis for interpreting soil-moisture trends and for possible application of the data to other situations.

STUDY AREA

The study area is in southern Robertson County, Texas, 20 miles northeast of College Station. The site had not been burned or excessively grazed for 10 to 15 years. It is fairly representative of some 4,450,000 acres of woodland in the East Texas Post Oak Belt.

The study was conducted on four 1-acre plots located within four adjacent 5-acre blocks.

Vegetation

The vegetation of the area is typical of an upland site of the Post Oak Belt. Dominant trees are post oak (*Quercus stellata* Wangenh.) and blackjack oak (*Q. marilandica* Muenchh.), with winged elm (*Ulmus alata* Michx.), gum bumelia (*Bumelia lanuginosa* (Michx.) Pers.) and black hickory (*Carya texana* Buckl.) as associated species. Basal area averaged 65 square feet per acre on unthinned plots but had been reduced in 1951-52 to 26 square feet on the thinned plots and to zero on the clearcut areas. By 1954 growth on residual trees in the thinned stands had doubled (5)[3], probably reflecting a considerable expansion of root systems.

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[1] This study was conducted in partial fulfillment of the requirements for the Ph.D degree at A & M College of Texas, College Station, Texas. The author wishes to acknowledge the aid of Dr. Robert A. Darrow and Wayne G. McCully in planning and conducting the studies, and the cooperation of Mr. Frank Seale in making the land available.

[2] East Texas Research Center, maintained at Nacogdoches, Texas, by the Southern Forest Experiment Station in cooperation with Stephen F. Austin State College.

[3] Underscored numbers in parentheses refer to Literature Cited, p. 11.

The chief understory shrubs were yaupon (*Ilex vomitoria* Ait.), French mulberry (*Callicarpa americana* L.), tree sparkleberry (*Vaccinium arboreum* Marsh.), and hawthorn (*Crataegus* spp.).

Grasses constituted 95 percent or more of the herbaceous cover. Little bluestem (*Andropogon scoparius* Michx.) comprised 70 to 85 percent of the forage in 1951 and 1952.[4] Oven-dry forage in 1951 prior to treatment ranged from 385 to 545 pounds per acre. Reduction in overstory densities greatly stimulated forage growth in 1953 and 1954[5] (6), production in 1954 measuring 209, 484, and 1,106 pounds per acre respectively on the undisturbed, thinned, and clearcut areas.

Other perennial grasses making up the herbaceous cover consisted of paintbrush bluestem (*A. ternarius* Michx.), yellowsedge bluestem (*A. virginicus* L.), paspalums (*Paspalum* spp.), panicums (*Panicum* spp.), Indiangrass (*Sorghastrum nutans* (L.) Nash.), tall dropseed (*Sporobolus asper* Kunth), brownseed paspalum (*P. plicatulum* Michx.), purpletop (*Tridens flavus* Hitchc.), longleaf uniola (*Uniola sessiliflora* Poir.), beaked panicum (*P. anceps* Michx.). Increases in paspalums and panicums were observed in 1953 and 1954.

Topography and Soils

The topography is gently rolling with an easterly exposure. The soils are Susquehanna-like or of the Susquehanna series of the Red and Yellow Podzolic group, having a gray sandy surface soil that averages about 6 inches in depth. The clay subsoils range in color from red to yellow, with conspicuous mottling at lower depths. They are massive and sticky when wet, become very hard upon drying, and swell and shrink considerably. After a substantial rain, the upper profile remains waterlogged for several days, indicating a very slowly permeable subsoil.

Physical properties of the soil were determined on four replications of the three oak treatments (table 1) 24 to 26 months after the oaks had been cut. Soils on cleared sites showed very significantly[6] higher bulk density at 0 to 6 inches, very significantly lower percentage of total aggregates at 6 to 12 inches, and significantly higher noncapillary and lower capillary pore space at 12 to 24 inches than those on thinned sites. Differences from the unthinned sites were similar except for noncapillary pore space, which was not significant. In other respects, the soil physical factors did not differ significantly.

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[4] Koshi, P.T. An evaluation of forage production under various densities of oak woodland. Master's thesis, A & M College of Texas, College Station, Texas, 62 pp. 1953.

[5] Koshi, P.T. An evaluation of forage production, vegetational composition, tree growth, and physical characteristics of soils under varying densities of oak woodland overstory. Ph.D. dissertation, A & M College of Texas, College Station, Texas, 116 pp. 1957.

[6] Where differences are described as significant, the 5-percent level of significance by analysis of variance is implied. Highly or very significant implies the 1-percent level.

Table 1.--Physical properties of soils

Soil layer and oak treatment	Textural class	Analysis: Sand	Analysis: Silt	Analysis: Clay	Total aggregation	Pore space: Noncapillary	Pore space: Capillary	Pore space: Total	Bulk density
		Percent	Percent	Percent	Percent	Percent	Percent	Percent	Grams per cc
0- to 6-inch layer									
Oaks undisturbed	Sandy loam	71.4	21.1	7.5	(1)	12.0	29.4	41.4	1.45
Oaks thinned	Sandy loam	69.6	23.1	7.3	(1)	11.0	31.9	42.9	1.43
Oaks clearcut	Sandy loam	69.1	23.5	7.4	(1)	11.4	28.3	39.7	1.52**
6- to 12-inch layer									
Oaks undisturbed	Clay	35.8	11.4	52.8	39.1	10.2	38.3	48.5	1.41
Oaks thinned	Clay	34.7	10.7	54.6	46.6	9.5	38.4	47.9	1.42
Oaks clearcut	Clay	40.4	12.6	47.0	31.8**	10.6	38.1	48.7	1.37
12- to 24-inch layer									
Oaks undisturbed	Clay	31.9	9.1	59.0	31.8	8.8	41.9	50.7	1.42
Oaks thinned	Clay	35.6	11.2	53.2	37.6	7.4*	40.3	47.7	1.46
Oaks clearcut	Clay	37.0	11.9	51.1	22.8*	9.3	36.3*	45.6	1.49

[1] Not determined for surface soils, which were primarily of single-grain structure.
* Difference from comparable statistics for other treatments significant at 0.05 level.
**Difference from comparable statistics for other treatments significant at 0.01 level.

It is not certain whether the differences in soils were inherent in the sites, or developed after treatment. They may have resulted from compaction due to heavier grazing (cattle were attracted by more abundant forage in the disturbed plots), and to changes in water regime within the soil.

Important equilibrium points of the moisture-tension curves are presented in Table 2. Soils under the three oak treatments had quite similar waterholding capacities. The upper 24 inches of the profile was estimated to hold 8.4 to 9.0 inches of water at field capacity

Table 2.--Average soil-water contents, by soil horizon and oak treatment, at indicated tension values

Profile horizon (inches)	Saturation (0.00 atm.)		Field capacity (0.04 atm.)		Permanent wilting point (15.00 atm.)		Available water-holding capacity (between 0.04 and 15.00 atm.)	
	Percent	Inches	Percent	Inches	Percent	Inches	Percent	Inches
0- to 6-inch layer								
Oaks undisturbed	28.9	2.5	20.6	1.8	1.8	0.2	18.8	1.6
Oaks thinned	30.2	2.6	22.4	1.9	1.9	.2	20.5	1.7
Oaks clearcut	26.0	2.4	18.6	1.7	1.8	.2	16.8	1.5
6- to 12-inch layer								
Oaks undisturbed	35.2	3.0	27.7	2.3	20.8	1.7	6.9	.6
Oaks thinned	34.0	2.9	24.8	2.3	20.8	1.8	4.0	.5
Oaks clearcut	36.1	3.0	28.2	2.3	17.9	1.5	10.3	.8
12- to 24-inch layer								
Oaks undisturbed	36.0	6.1	28.5	4.8	21.9	3.7	6.6	1.1
Oaks thinned	32.9	5.8	28.1	4.8	20.3	3.6	7.8	1.2
Oaks clearcut	30.4	5.4	24.5	4.4	19.5	3.5	5.0	.9
Total profile horizon								
Oaks undisturbed	...	11.6	...	8.9	...	5.6	...	3.3
Oaks thinned	...	11.3	...	9.0	...	5.6	...	3.4
Oaks clearcut	...	10.8	...	8.4	...	5.2	...	3.2

(0.04 atm. tension), and 5.2 to 5.6 inches at approximate wilting point (15 atm. tension), leaving an indicated 3.2 to 3.4 inches available to plants. The high clay content of the subsoils undoubtedly accounted for the high amount of water held at permanent wilting point, and the low amounts of available water.

The moisture content at saturation (0.00 atm. tension) was significantly higher under the undisturbed stands than on the clearcut sites but not significantly different from that for the thinned site at 12 to 24 inches. This difference affects temporary waterholding capacity, but may not greatly alter the amount available to plants.

Weather

The normal precipitation for College Station, Texas, is 38.94 inches annually. There was an excess of 5.67 inches in 1953, whereas 1954 was 11.04 inches below normal. Precipitation was well distributed during 1953. In 1954 only 0.14 inch fell in June and in August, while February and March had less than 1 inch each.

Mean maximum temperature during July and August, when soil moisture is expected to be at a critically low level, was 93.2°F in 1953, 96.5°F in 1954.

PROCEDURE FOR STUDYING FIELD MOISTURE

Soil-moisture measurements were made on two plots of each of the three oak treatments. Soil-moisture units of the Colman electrical-resistance type, equipped with thermistors (1), were installed at three selected depths: 2 inches above, 2 inches below, and 12 inches below the top of the subsoil. In calculations of moisture content of the soil profile, these locations were assumed to reflect conditions in the 0- to 6-, 6- to 12-, and 12- to 24-inch levels, respectively.

The moisture units were installed centrally in openings in the stand; these openings were at least 15 to 20 feet in diameter. At one opening in each plot, two units were buried at each depth. In two other openings, single units were installed at each depth. Readings from the four units at each level on each plot were averaged. Measurements were made weekly or biweekly from May to November 1953 and from March to August 1954, and monthly from December 1953 through February 1954.

The relationship between soil-moisture content and electrical resistance of the Colman units was determined by laboratory calibration from composite soil samples for each depth. Approximately 1 kilogram of soil was packed with a test unit in a quart container to approximate field conditions. Resistance readings and weights were taken at 24-hour intervals after saturation until the soils were dry. Two dry-down cycles were employed in the calibration procedure.

The resistance readings obtained in the calibration and field measurements were corrected to 60°F. with the aid of tables supplied by the Vicksburg Research Center of the Southern Forest Experiment Station. Moisture percentages determined in this manner were converted to inches of water by methods outlined by Land and Carreker (8) and Reinhart (9).

Soil-moisture trends were evaluated principally by graphic analysis.

RESULTS

Moisture trends under the oak treatments, together with rainfall at College Station, Texas, are graphed in figures 1 and 2.

Soil Moisture Regime

Total profile.--Throughout the period of observation soils of the cleared plots had more moisture than those of the undisturbed plots, while the thinned plots were intermediate. Differences tended to be greatest at high water contents, and least at times of drought. During July and August 1954, after a prolonged drought, there was little difference in residual moisture among the three treatments.

Differences in total moisture resulted partly from differential net accretion rates after rains, and partly from different depletion trends. After rains in June, September, and October of 1953, accretion in the cleared plots exceeded that on the undisturbed areas; the thinned plots also acquired more water than the undisturbed from the June and October rains. By contrast, after a heavy rain in May 1954 accretion was greatest on the thinned plots, intermediate on the undisturbed, and least on the cleared plots.

Depletion trends were roughly parallel for the three treatments. During three of the five depletion periods the cleared plots lost more moisture than the untreated. The reverse was true for the May-June period of 1953 and the January-April period in 1954. Except for the July-August period in 1953, depletion trends for the thinned plots were more like those for the undisturbed plots than for the cleared plots.

When the cleared plots lost less moisture than the others, their rate of depletion was less. But during summer periods, when more moisture was lost from the cleared plots, rates of loss were similar but cleared plots continued to lose moisture longer. Thus, during May-August 1954, rapid depletion continued more than two weeks later on the cleared areas than on the other treatments.

The undisturbed and thinned plots reached approximately the same minimum--3.2 inches of residual moisture--in August and October 1953 and July-August 1954. The depletion curves also flattened out

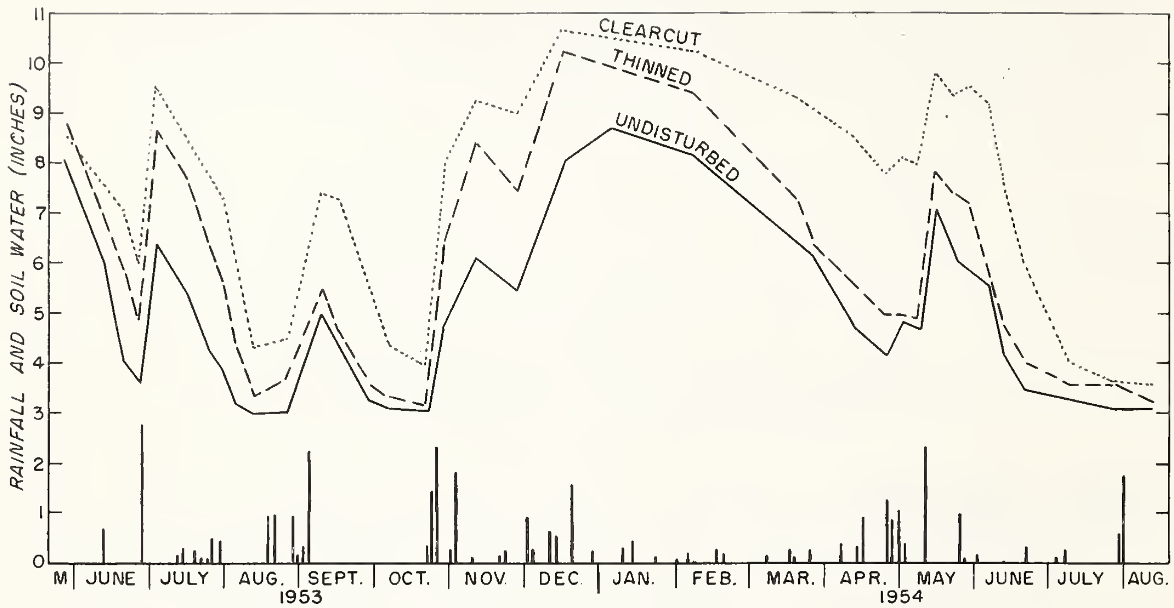
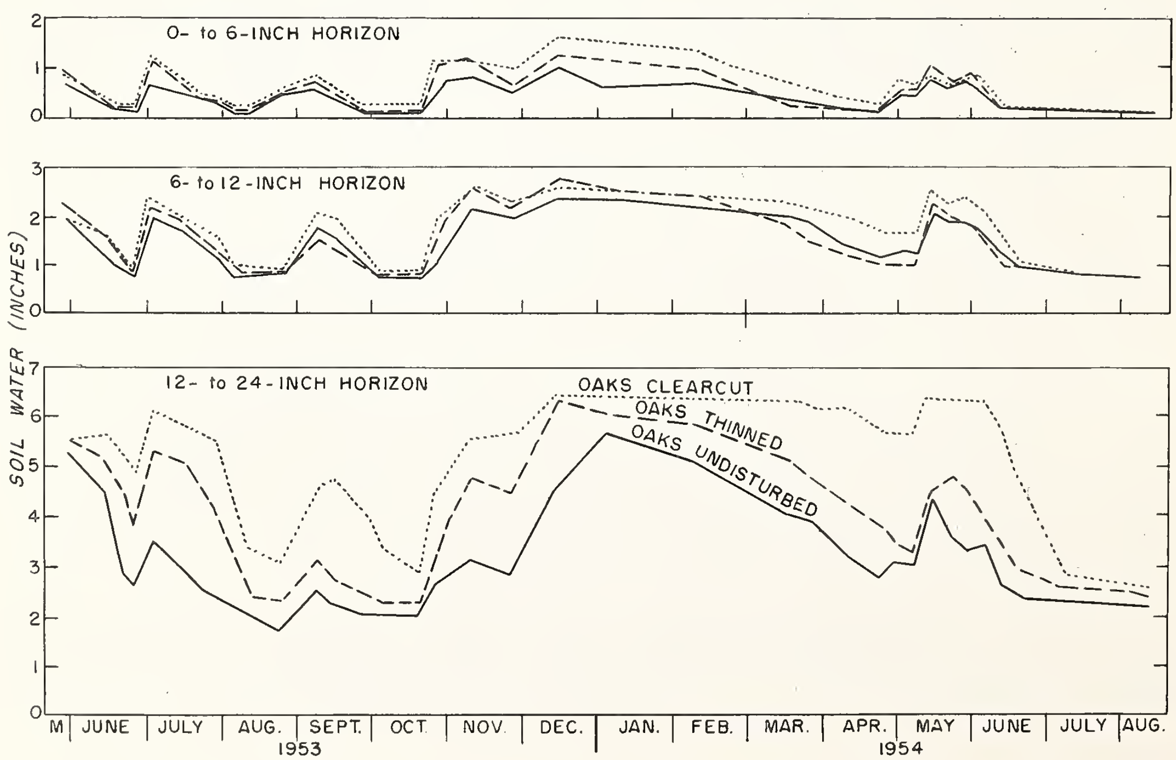


Figure 1.--*Water in upper 24 inches of soil under three densities of oak overstory. Rainfall at College Station, Texas.*

Figure 2.--*Water in various soil horizons under three densities of oak overstory.*



for the cleared plots at about this same moisture content in 1954. These levels are about two inches below the nominal permanent wilting point as determined in the laboratory.

0- to 6-inch depth.--Minimum moisture levels at this depth were close to laboratory determination and nearly identical for all treatments and all depletion periods. After rains, thinned and cleared plots absorbed and retained more moisture in this level than did undisturbed plots.

6- to 12-inch depth.--Here again consistent minima were reached during each depletion period, except that the cleared plots did not fall so near the minimum in April 1954. The leveling-off point (July-August 1954) is nearly an inch below the laboratory-determined permanent wilting point. Accretions and maximum moisture levels on the three treatments were more consistent than at either of the other soil levels.

12- to 24-inch depth.--This portion of the profile contributed most to the determination of total moisture trends, not only because of its greater thickness, but also because the major differences due to treatment appeared most prominently in it.

The cleared plots again contained the most moisture, and the undisturbed plots the least. Moisture on the undisturbed and thinned plots followed trends quite consistent with those of the upper horizons and the total profile. On the cleared plots, however, moisture content increased more rapidly in the fall of 1953, reaching 6.4 inches by December 1953. It remained at this level, with little deviation, until June 1954, but by the second week in July this moisture had been depleted to approximately the same level as for the other two treatments.

Periods of Soil-Moisture Stress

The effect of moisture on tree and forage growth may be closely related to the frequency and duration of droughts.

To identify such periods, it was assumed that plants were adequately watered as long as rapid depletion occurred, and that reduced depletion rates signified that moisture was too low to be readily available to plants. In the light of this assumption, the permanent wilting points determined in the laboratory seemed to be too high for the soil and vegetation under consideration. Periods of soil-moisture stress were determined, therefore, from figures 1 and 2, with the lower limit of available water being taken as the point where drastic reduction in depletion occurred. The results appear in table 3.

Under the undisturbed stand, two periods of soil-moisture deficiency occurred in 1953, for a total duration of 53 days. At 26 square feet of overstory basal area the 1953 stress period was reduced by 10 days, while on the clearcut areas only 4 days of stress occurred.

Table 3.--Duration of soil moisture deficiency for three oak treatments, with flexpoints of depletion curves taken as permanent wilting points

Years	Undisturbed	Thinned	Clearcut
	Oak treatment		
	Days	Days	Days
	TOTAL PROFILE		
1953	53	43	4
1954	53	40	16
Total	106	83	20
	0- TO 6-INCH DEPTH		
1953	54	51	44
1954	76	73	44
Total	130	124	88
	6- TO 12-INCH DEPTH		
1953	42	41	18
1954	36	36	36
Total	78	77	54
	12- TO 24-INCH DEPTH		
1953	66	46	4
1954	53	35	16
Total	119	81	20

In 1954 stress in the undisturbed and thinned stands developed in June and continued for 53 and 40 days respectively to the conclusion of the study on August 13. On the clearcut plots the deficiency level was reached July 28.

On all treatments, stress was most prolonged in the 0- to 6-inch horizon. Stress periods at the 0- to 6- and 6- to 12-inch levels did not vary greatly with treatment, but at the 12- to 24-inch level stress periods were shortest where the overstory had been thinned or removed.

DISCUSSION

Differences in moisture regime revealed in this experiment are believed to be related primarily to differences in vegetation resulting from the overstory treatments. The tree roots extended into and to some extent proliferated through the second foot of soil. The observations of soil moisture suggest that throughout most of the study grass roots were confined chiefly to the upper 12 inches of the soil profile.

Except for the initial measurements, and the low-level measurements in July-August 1954, the moisture content of the soil profile was consistently highest in the cleared plots, intermediate in the thinned plots, and lowest in the undisturbed stands. While there were gross differences in rates of accretion as well as depletion, the frequency of observation was insufficient to establish whether differences in instantaneous accretion rates occurred. Thus the accretion on all treatments in the fall of 1953 was the resultant between water added by rainfall and moisture lost through evapotranspiration prior to measurement. It is entirely possible, therefore, that evapotranspiration from tree leaves might have been sufficient to account for the apparently lower accretion rates on the thinned and undisturbed plots. Also, some precipitation may have been lost from interception.

Maximum total depletion rates varied surprisingly little between treatments. When moisture was abundant, all three stands reached growing-season depletion rates close to 0.2 inch per day. Under all three treatments depletion continued at high rates until soil moisture

was virtually exhausted. In conjunction with findings of Veihmeyer and Hendrickson (10), Gaiser (4), Fletcher and McDermott (3), and Zahner (11) these results indicate that, with either tree or grass vegetation, soil moisture may be utilized during the growing season at maximum rates until the wilting point is nearly reached.

In winter, depletion rates were distinctly higher on the wooded than on the cleared plots--approximately 0.04 to 0.05 inch per day, in contrast to 0.01 to 0.02 inch. These differences suggest some absorption of moisture from the soil and perhaps evaporation from stems of hardwood trees.

Differences in moisture content of the profile result primarily from differences in the 12- to 24-inch horizon. In the 0- to 6- and 6- to 12-inch horizons the trends are remarkably uniform for all three oak treatments, but in the 12- to 24-inch horizon the moisture losses on the cleared plots were distinctly less than for the other two treatments. On the cleared plots this horizon was saturated throughout much of the winter and spring of 1954. It did not reach the wilting point until late in the July-August drought of 1954, nearly a month after available moisture at this level had been depleted in the undisturbed plots.

It seems reasonable to conclude that roots of trees withdrew water from all three soil horizons, as reported by Gaiser (4) for the oak forests in Ohio, and that the shallower grass roots drew water primarily from the upper 12 inches. In Efimova's studies (2), herbaceous vegetation extracted moisture rapidly from the surface 1/2 meter, whereas trees utilized moisture uniformly from a depth of 1 meter. It was evident from the present study, however, that under stress, as during the summer of 1954, the grass roots could exhaust the moisture from at least the upper two feet of the profile. In this geographic region any type of vegetation that fully occupies the site is evidently capable of utilizing all of the season's moisture.

The differences in physical properties of the soil two years after cutting may or may not be attributable to treatment effects, since no determinations were made prior to treatment, but some of the variations may reflect inherent soil differences. Cleared plots differed significantly from the undisturbed or thinned plots, or both, in having a lower percent of aggregation at the 6- to 12- and 12- to 18-inch levels, in lower capillary pore space at the 12- to 18-inch level, and higher bulk density at the 0- to 6-inch level. These differences could have been related to the clearing operation and subsequent soil changes.

Compaction of the surface is believed to have resulted from increased trampling by livestock attracted to the improved forage and possibly to reduced incorporated organic matter.

Since the indicated changes are in the direction of poorer internal drainage, some of the differences in depletion rates may reflect different rates of percolation to soil horizons below those measured. Such effects, however, probably could not account for differences in depletion of the observed magnitude.

The prolongation of near-saturated conditions in the 12- to 24-inch horizon on the clearcut plots for nearly six months may affect root development and soil hydrology. The depletion pattern in the 12- to 24-inch horizon under clearcutting definitely indicates lack of root activity. Kramer (7) states that the physiological effect of poor aeration is two-fold with respect to absorption of water: the metabolism in the root cells is reduced, and there is an increased resistance of the root to entry and transmission of water. Root penetration may also have been restricted as a result of poorer soil structure.

Detention and retention storage capacities are very limited when profiles are saturated. During the winter, when excessive rains are most frequent, the cleared sites had considerably less capacity for storing additional rainfall than the wooded areas.

SUMMARY AND CONCLUSIONS

From May 1953 to August 1954 a study was made of soil-moisture trends under undisturbed, thinned, and cleared post oak stands on Susquehanna-like soils in Texas.

Throughout most of the test, the moisture content of the upper two feet of the soil profile was highest in the cleared, intermediate in the thinned, and lowest in the undisturbed areas. Most of the difference occurred in the 12- to 24-inch horizon.

Roots of grasses were active chiefly in the upper 12 inches of the soil profile, while the tree roots also withdrew water consistently from the 12- to 24-inch horizon.

Moisture content at 15.0 atmospheres pressure was not an accurate index of wilting point, since rapid depletion continued to considerably lower levels.

Either grass or tree vegetation is capable of withdrawing all available moisture from the entire upper 24 inches of the soil profile. Trees withdrew water from upper and lower horizons simultaneously; grasses tended to exhaust the upper horizons before making substantial withdrawals from the 12- to 24-inch levels.

Maximum daily depletion rates occurred during the growing season and were in the magnitude of 0.2 inch for both grass and tree vegetation. In winter the wooded plots lost moisture at rates of 0.04 to 0.05 inch daily, in contrast to 0.01 to 0.02 inch for the cleared plots.

The number and duration of periods of moisture stress, during which little or no moisture was available in the upper 24 inches of soil, were reduced by thinning and clearing.

The essentially saturated condition of the soils on the cleared plots throughout the winter season may have limited root development in the 12- to 24-inch level by reducing soil aeration. The saturated soils of the clearcut plots afforded less opportunity for storage of excessive rainfall, and thereby offered less check to runoff and flooding.

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